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A Structure Comparison of two Approaches to LCA Inventory Data, Based on the MIET and ETH Databases

Ignazio Mongelli[1]*, Sangwon Suh[2] and Gjalt Huppes[2]

[1] Dept. of Commodity Science, Faculty of Economics, University of Bari, via C. Rosalba 53, 70124 Bari, Italy
[2] Centre of Environmental Science, Leiden University, Einsteinweg 2, 2333 CC Leiden, The Netherlands

* **Corresponding author** (ignaziomongelli@dgm.uniba.it)

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Abstract

Goal and Scope. This study compared two different approaches to general inventory data in LCA, one involving the process-based ETH 96 database and the other an environmentally extended Input-Output table for the US, referring to MIET (*Missing Inventory Estimation Tool*) 2.0. The purpose of the present paper is to highlight and explain some of the differences between the two approaches, in order to give LCA practitioners a clearer idea of the advantages and limitations of using Input-Output analysis combined with process LCA.

Methods. The comparison was made despite substantial differences between the two approaches, through a reduction and reclassification of the ETH process technology matrix to fit the Input-Output classification scheme and by concentrating on the structure of the processes rather than their absolute values. The structure is described in terms of the percentage of the CO_2 contribution to the total emission by all processes involved in the supply chain. An input and output structure comparison was carried out between ETH 96 and MIET 2.0, to extract information about their structures.

Results and Discussion. The results of the study show that, despite their methodological differences, MIET 2.0 and ETH 96 show substantial similarities in their overall structures. There are also differences in the structure of the two databases, and most of them have occurred randomly, while, for certain particular sectors, the differences are rather persistent. Especially the contributions by capital goods are constantly lower in ETH 96 database and *vice versa*. The results imply possible systematic truncation in process LCA databases, especially for a few sectors such as capital goods.

Recommendation and Perspective. Hybrid analysis can overcome the problem of incompleteness in process LCA, while avoiding such disadvantages of IOA as aggregation problem.

Keywords: Correlation study; ETH 96 database; Input-Output analysis; inventory data; MIET (Missing Inventory Estimation Tool) 2.0

Introduction

It has repeatedly been pointed out that one of the main problems in LCA is the arbitrary system boundary definition [1–5]. ISO 14041 states that: "*Ideally the system should be modelled in such a manner that inputs and outputs at its boundaries are elementary flows.*" [6]. In theory, this means that all processes directly and indirectly linked to the product system at hand should be included in the system, expanding its width and depth. This type of LCA requires practitioners to consider virtually the entire economy, as ultimately almost all processes are linked. It is quite easy to imagine that this is complex, expensive, and practically impossible.

Recognizing these difficulties, the same ISO 14041 states that the practitioners can decide the level of detail of the study and exclude some flows or processes that will not change the overall conclusions of the study. The choice of the boundary, and consequently of the flows to be cut off, can be made by applying the so-called cut-off criteria; either those suggested by the same ISO standards, based on energy, mass or environmental relevance, or those proposed in the scientific literature [7]. Boundary selection is done as an iterative process. Starting from an initial boundary including the main process and some other directly linked upstream and downstream links in the supply chain, the boundary definition process continues by progressively including the processes whose contributions to the overall environmental impacts of the product system are considered to be relevant. Despite the efforts to objectively draw a system boundary of a product system, complying the ISO requirements for system completeness still seems to be quite difficult [5]. Inevitably, some processes are excluded, leading to an underestimation of the environmental burdens, the so-called truncation error, which, depending on the processes, could be as much as 50% of the total environmental impact [1].

As recently proposed, a way to cope with the truncation problem is to combine environmentally extended Input-Output analysis with traditional process-based LCA [4,5]. The resulting *hybrid* methods can be used to obtain more complete inventory results by recovering the cut-off flows using input-output data [4,8–10]. Hybrid methods use the strengths of both approaches to achieve a detailed and more complete analysis [4,5,11].

The present study compares two LCI databases, viz., the process-based LCI database and environmentally-extended Input-Output database. For the former, the matrix approach proposed by Heijungs was applied to the ETH 96 database (referred to below as ETH), which is one of the most widely used LCI databases [12,13]. The matrix approach allows us to overcome the problem of closed loops, which is another source of incompleteness in conventional LCA based on the process-flow diagram approach; see Suh and Huppes for details [11]. With the virtue of matrix approach it utilises,

the database is directly applicable in the *integrated hybrid method* [4]. For the Input-Output database, the present study makes use of the MIET 2.0 database (referred to below as MIET) [14]. MIET is based on a 91×91 US commodity–by-commodity Input-Output table, derived from the *make and use* tables published by the *Bureau of Economic Analysis* (BEA) in 1996, and various environmental statistics covering more than 1000 environmental intervention data. In the present study, we only used CO_2 emissions data as an indicator for a structural comparison of the two databases. In order to examine the unique differences of the two databases, we compared the input and output structures, rather than their absolute values, of some basic commodities or processes, expressed in CO_2 embodiments of the commodities. Input structure here means the relative contribution of each input to a product system to its overall CO_2 emission [15]. Output structure here refers to the relative contribution of a particular commodity, again expressed in terms of embodied CO_2, to all the other commodity groups. The input structure in a matrix is derived from the coefficients of its columns, the output structure from the coefficients of its rows.

However, a direct comparison between the two databases is not easy, as there are substantial differences between the approaches, such as those related to data sources, level of specificity and general accounting framework. Therefore, we have first transformed the two databases in such a way that their structures can be compared on the basis of the same classification system. The ETH technology matrix was aggregated from 1163 processes to 91, which is the classification used in the Input-Output table at stake, by using a permutation matrix (see section 2.3 below). After this reclassification and aggregation, the two technological matrices presented comparable Input-Output structures. And second, we have extracted relative contribution data, instead of absolute values, from the matrices to highlight the structural differences. A correlation study was conducted for each of the corresponding columns, to assess the input structures of the two databases, while the output structures were analysed using a graphical representation.

The aim of the analyses is to highlight similarities and differences between the two approaches and guide LCA practitioners in choosing the database that is of better relevance for the specific goal and scope of a study.

This article is structured as follows: section 1 describes the general features of ETH and MIET. Section 2 presents a brief description of the computational features of the process-matrix approach for LCA and Input-Output analysis as well as explaining the algebraic methodology applied in the permutation to obtain comparable matrices. The results of the correlation study and of the input and output structural comparisons are discussed in section 3, while the fourth and final section presents the conclusions of the study.

1 Structure and Features of the ETH 96 and MIET 2.0 Databases

1.1 General features of MIET 2.0

MIET is an environmentally extended Input-Output database that is designed to assist IO-LCA and tiered hybrid LCA studies. It was published in 2001, and currently has more than 500 subscribers worldwide. It uses a 1996 U.S. Input-Output table based on a 91×91 classification and corresponding environmental databases, including

– Toxic Release Inventory (TRI 98), for toxic substances [16],
– Air Quality Planning and Standards (Airs) EPA, for conventional pollutants [17],
– Energy Information Administration (EIA), for energy consumption [18],
– National Centre for Food and Agricultural Policy (NCFAP), for pesticide use [19].

The number of environmental interventions compiled exceeds 1000 [14]. The main features of the MIET database are as follows:

– Based on a consistent commodity-by-commodity framework,
– Either consumers' or producers' price can be used,
– Contains around 100 widely used impact assessment methods,
– Officially published statistical sources are used,
– Avoided impact allocation,
– Capital goods (investments by sectors) are endogenised in the monetary transaction table.

The Input-Output table used in MIET is derived from the *make and use* tables published by the BEA in 1996. According to the most recent revision of the System of National Accounts in 1993, accepted by the European Community as part of SEC95 [20], the national accounting system should be based on *make and use* type tables.

Although the utilisation of *make and use* tables makes it possible to consistently deal with secondary products and scraps, these tables require further treatments to construct a commodity-by-commodity technology matrix [21]. This requires assumptions on the way how inputs of an industry are allocated over its multiple outputs. Two different assumptions are the most widely used: the *commodity-technology* assumption (i.e. a product has its own input structure in whichever industry it is produced) and the *industry-technology* assumption (i.e. multiple outputs of an industry have the same input structure) [22]. MIET uses both assumptions, while the public version is based on the latter.

Our study used the MIET, derived using the commodity-technology assumption, which is analogous to the 'avoided impact' allocation method in LCA. On the basis of this allocation procedure, the emissions due to the production of secondary products have to be subtracted by the total sectorial emissions in order to account only for a primary product and its environmental burden. Emission intensities related to secondary products are derived by referring to the sector, which produces them as primary products [14,22,23]. In other words, the environmental burden related to secondary products is allocated in those sectors that produce those products as primary products (see the MIET 2.0 user's guide for further explanation).

The last feature of MIET is its inclusion of capital goods (or investments) in the monetary transactions among the Input-Output sectors. The Capital Flow Table (CFT 1992) [24] was used to adjust the monetary flows of the Input-Output table in order to include purchases and supplies of equipment and new structures. This accounts even for the emission of CO_2 caused by the production of these inputs, which is generally not included in the conventional Input Output

tables. Capital goods purchases and supplies included in CFT refer to 1992, which means that what has been used is the '*investment intensity*' by sector, assuming that this intensity, rather than the absolute amount, had not changed by 1996. MIET 2.0 has been updated using the 1998 IO table and corresponding environmental databases based on a 480×480 commodity classification, and is now included in LCA software packages [25,26] However, this version was not available at the time this analysis was carried out and was therefore not considered in the present study.

1.2 ETH 96 general features

ETH is one of the most commonly used databases for LCA. An update will become available soon, but was not available when the present analysis was carried out. However, we do not expect the structure of the update to be very different from the current one. It was designed primarily for energy systems, and its inventory tables include the emissions/resources consumption linked to the entire supply chain of the various energy production processes. All activities related to energy production are considered, referring to the Swiss and, more generally, Western European situation. ETH is subdivided into the following categories:

- energy carriers;
- basic materials;
- transport activities;
- general services;
- electricity;
- oil;
- natural gas;
- coal;
- nuclear energy;
- renewable energy sources, including hydroelectric power, wood, solar energy (photovoltaic and solar thermal) and wind energy;
- geothermal;
- combined production (heat and power);
- waste treatment.

For all these categories, it includes the entire supply chain. For example, the 'Energy Carriers' category refers to the extraction and production of energy commodities: oil products (fuel oil, gasoline, diesel, etc.), coal products (hard coal, lignite, etc.), natural gas, uranium and wood. All activities related to the production and supply of these energy commodities are included. Regarding the transport activities, it includes several means of transport: road-based (private car, delivery van, lorries (16t, 28t and 40t)), railway-based (diesel and electric traction), water-based (high sea and inland, oil tanker and freighter) and pipeline-based (on- and offshore pipelines and gas pipelines). Moreover, the inventory tables include the construction of infrastructure elements (bridges, tunnels, harbours, railway tracks, etc.), the manufacturing of equipment (locomotives, cars and lorries, ships, etc.) as well as end-of-life aspects. [13].

2 Computational Structure of the Compared Approaches

2.1 MIET computational structure

MIET is based on a total multiplier matrix obtained through the well-known Leontief inverse, on which Input-Output analysis is based. The basic equation, in matrix notation, for the Input-Output analysis is:

$$x = (I - A)^{-1}\, y \qquad (1)$$

where x is the variation in the total output, A is the direct coefficient matrix (obtained by the Input-Output transaction table) I is the identity matrix and y is the final demand vector. The inverse matrix, $(I - A)^{-1}$, known as the Leontief inverse, represents the total requirements. For further explanation about Leontief Input-Output analysis, see Miller and Blair [27].

The premultiplication of the Leontief inverse by an environmental matrix containing the intervention related to one monetary unit for each sector results in the total (i.e., direct plus indirect) environmental intervention related to one monetary unit of output produced by each sector in a steady-state period.

$$E = F\,(I - A)^{-1} \qquad (2)$$

In the present work, the F matrix in Eq. (2) includes only the emissions of CO_2 for each sector. Although it is therefore a vector, we use it in diagonal form (a matrix in which all the elements are zero, except for the main diagonal including the CO_2 emissions of each sector). The E matrix has the same dimension as the Leontief inverse and shows the input structure of the 91 commodities included in the US Input-Output table, in terms of embodied CO_2.

2.2 LCA matrix approach based on the ETH database

ETH database utilises a matrix approach developed for LCA [12,28]. The *technology matrix* used in this approach is an algebraic representation of the flows of commodities between industrial processes (energy, materials, services) in physical units. The technology matrix is generally square and is in dimension of economic flows-by-processes (see Heijungs and Frischknecht for the case of a non-square technology matrix) [29]. The use of commodities by processes are noted with negative values, while production was positive in the technology matrix. The basic equation of this framework is:

$$g = BA^{-1} f \qquad (3)$$

Where B is the intervention matrix showing pollutant emissions or resources use for one unit of each process, A^{-1} is the inverted technology matrix, f is the final demand vector (functional unit) and g is the Life Cycle Inventory. The life cycle inventory problem is solved by finding the g, which is the solution of Eq. (3). Without going into a detailed description of this framework, the main advantage of using a matrix is that the closed-loops problem, or recursive flows between processes (for instance, steel uses coal as input while coal needs as an input as well), is elegantly resolved by using the matrix approach [11]. Using the matrix approach, for example, the coverage of the product system is stretched infinitely around the upstream process relationships, which is difficult to attain using only traditional process-flow diagram approach. Although the matrix approach provides a higher level of completeness than the traditional flow-chart approach in terms of the order of upstream inputs considered (depth), the system boundary is constrained by the number of processes included in the technology matrix (breadth).

The basic data required for the analysis are directly drawn from the ETH database and CMLCA software was used for matrix calculation [30]. The pre-multiplication of the inverted technology matrix by the intervention matrix – in this case, a diagonal matrix just for CO_2 – results in an intensity matrix, with the same 1163 × 1163 dimension showing the CO_2 embodied in the processes included in the system. The equation for the intensity matrix M is as follows:

$$M = \hat{B}_{CO_2} A^{-1} \quad (4)$$

The hat (^) produces a diagonal matrix out of a vector.

2.3 Permutation matrix

In order to compare the ETH CO_2 multiplier matrix with that of MIET, we transformed the ETH technology matrix and the corresponding environmental matrix to the level of aggregation used by MIET. The number of commodities classified in the ETH matrices was reduced from 1163 to 91. This reduction was achieved by aggregating the economic flows (rows) of the ETH according to the Input-Output classification scheme.

The reclassification of the ETH multiplier matrix was obtained through a premultiplication of the right-hand side of equation (4) by a *permutation matrix P*. The permutation matrix P is rectangular, with a dimension of 1163×91. The p_{ij} coefficients of the permutation matrix are 1 or 0, depending on the particular Input-Output commodity sector to which the ETH economic flow belongs:

– *if the economic flow (or process) does not belong to the IO commodity sector, then* $p_{ij} = 0$
– *if the economic flow (or process) belongs to the IO commodity sector, then* $p_{ij} = 1$

Since the ETH multiplier matrix is pre-multiplied by P, the equation (4) becomes:

$$M = P' \hat{B}_{CO_2} A^{-1} \quad (5)$$

In equation (5), the superscript apostrophe means the transposition of P. By applying equation (5), the number of ETH economic flows is reduced from 1163 to 91. Note here that only CO_2 embodiments by input commodities to each process are aggregated by this operation, and no aggregations between processes are made here. As different processes in ETH database may have significant difference in their production volume in absolute term, aggregation between processes is not straightforward like the one in Eq. (5). In this way, it is possible to highlight which of the 1163 processes has the greatest correspondence and similarity with the Input-Output sectors included in MIET.

2.4 ETH and MIET correlation study

After the premultiplication described in equation (5), the coefficients of the multiplier matrix M are divided by the total of their columns. The generic elements of the resulting matrix M^* are obtained by:

$$(M^*)_{ij} = (M)_{ij} \Big/ \sum_i (M)_{ij} \quad (6)$$

In the same manner, the multiplier matrix E of MIET is normalised to the total of its 91 columns. The generic elements of the E^* matrix are obtained by:

$$(E^*)_{ij} = (E)_{ij} \Big/ \sum_i (E)_{ij} \quad (7)$$

After the application of equations (6) and (7), the resulting matrices M^* and E^* represent the percentage contribution of each input to their total CO_2 emission of each process.

A column-wise correlation analysis has been performed between matrix M^* and matrix E^*. The highest R^2 correlation values obtained by the column-wise correlation analysis among the 1163 processes (columns) of the M^* matrix and the 91 commodity sectors of the E^* matrix indicate the most similar processes in terms of their input structures on the basis of embodied CO_2.

3 Results

3.1 Absolute comparison between ETH and MIET

Although it is not considered as the main elements of the current study, an absolute comparison between the two databases is carried out mainly to check if there are extraordinary discrepancies between them. **Fig. 1** shows the CO_2 emission from seven background processes, corresponding to the same functional units of 1 m^3 for natural gas, 1 kWh for electricity production and 1 kg for all others. The conversion of the physical unit to monetary terms, which is necessary for the application of Eq. (2), was based on the price level for 1996, the same year used for the selected commodities in the US IO table. The statistical surveys used for the conversion prices are the statistics provided by the Energy Information Administration for the energy commodities (coal, electricity and natural gas), and the U.S. Geological Survey for the remaining commodities [31,32].

An absolute comparison between ETH and MIET in terms of functional units does not provide easily comparable results, because of, for example, the differences in their approaches, and the price inhomogeneity. In particular, typical sources of errors in comparing Input-Output based results with process analysis include:

– choice of average price (prices not homogeneous across the same sectors),
– standard errors of survey statistical data,
– time gap between the compilation of the data and the use of the table for IO analysis,
– composition of technology between the two geographical areas,
– cut-offs made in process LCA database,
– choice of allocation method,
– assumptions on imported goods.

The assumption about imported goods and the price inhomogeneity within an economic sector are considered to be the important sources of difference between MIET and ETH. Other sources of errors could be considerable as well, although

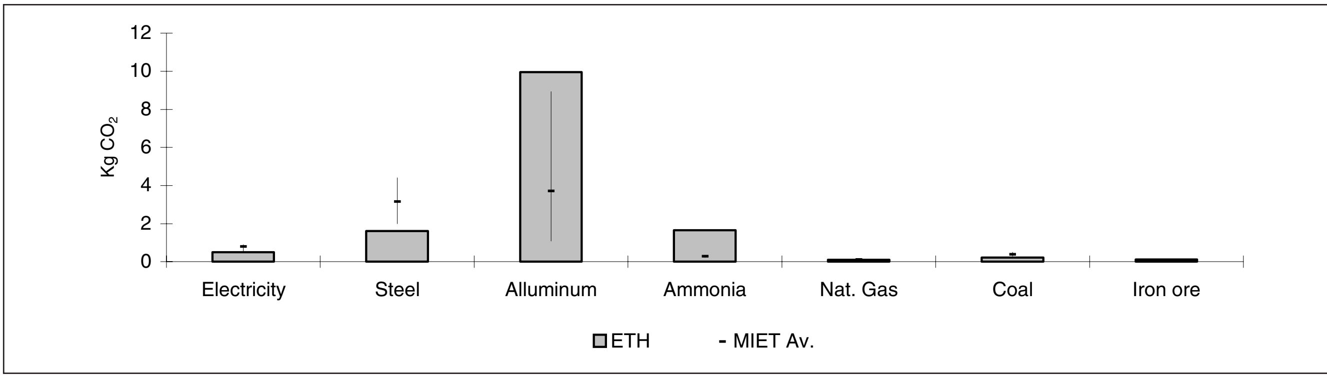

Fig. 1: CO_2 emissions calculated by ETH and MIET per kWh for electricity, m^3 for natural gas and kg for steel, aluminium, ammonia, coal and iron ore

they are not considered to be the dominant sources of errors. Firstly, the technological compositions of the two regions, which are the U.S. and western Europe, are more similar than any other regions in the world, except for a few sectors related to agriculture and energy, for example, and secondly, these versions of MIET and ETH shares more or less the same base year, so that temporal difference can be neglected.

MIET is based on the assumption that imported goods are produced with the same US technology, while ETH takes into consideration the geographical differences in the technologies applied. Moreover, MIET, like all monetary Input-Output analyses, refers to inter-industry flows expressed in monetary terms, and the basic assumption is that these monetary flows represent physical and technical input-output relationships among industries. The price inhomogeneity of commodities belonging to the same sectors, however, introduces uncertainty in the final results, whereas the higher level of specificity and the physical units used in ETH do not introduce this type of errors.

Due to these inherent differences, the absolute CO_2 emission figures for the sectors considered differ significantly between the two databases, although the patterns are rather similar (see Fig. 1). MIET shows higher results in only four of the seven categories compared, including electricity generation, steel production, natural gas and coal mining.

Fig. 1 compares the emissions calculated by ETH with those obtained through MIET, at different price levels for the same commodities in order to highlight how the results depend on the price.

The price of commodities depends on several factors, such as the end-user, the type of commodity or the geographical origin. For instance: prices of iron ores and natural gas vary within ranges of ±35% and ±40%, respectively, depending on the geographical origin of the ore (different US regions) and the end-user to whom the natural gas is delivered (residential or power plants); the price of an aluminium can may be more than double its average price, depending on its manufacturing features (aluminium plates, sheets, casts, etc.). Therefore, an absolute comparison between the two approaches relies heavily on the choice of price and consequently makes it difficult to draw meaningful general conclusions. Thus, the absolute comparisons are no longer pursued in this study and the following results are focused on the relative structural comparisons.

3.2 Column-wise correlation study and input structure comparison

A comparison of the input structure highlights the use of the 91 commodities as inputs by processes, expressed in terms of CO_2 embodiment. The processes with the highest R^2 coefficients, which means the most similar input structures between the two databases, are listed in **Table 1. Fig. 2** and **Fig. 3** show the input structure of these processes.

For the sake of a more convenient representation in the figures in this paper, the 91 commodity sectors have been further reduced to 15 categories, by aggregating and excluding some of them. In particular, the category named 'Capital goods' includes sectors like: 'New construction', 'Furniture and fixtures', 'Metalworking machinery and equipment', 'Electrical industrial equipment and apparatus' and 'Transport equipment'. Some of the sectors included in the 'Services' category are 'Wholesale and retail trade', 'Finance', 'Insurance', 'Advertising', 'Eating and drinking places' and 'Automotive and repair services'. The 'Transport (others)' category includes road and air transport, thus excluding pipeline transport for natural gas and petroleum.

ETH and MIET show similar *shapes* in these four graphs, which means that they have similar input structures. This conclusion is confirmed by the correlation value R^2 for these processes, which ranges from a minimum of 0.70 for 'Engines and turbines', which is known to be highly inhomogeneous, to a maximum of 0.99 for 'Primary iron and steel manufacturing', which is more homogeneous. The latter shows a very similar input structure if we exclude the contribution of the 'Others' category. For this category, the difference is due to the high relevance, in the value of ETH, of the 'Water and sanitary services' sector, which also refers to recycling and waste treatment processes.

Table 1: Highest R^2 coefficients (column-wise)

ETH processes	Sectors (processes)	R^2
Electro steel	Primary iron and steel manufacturing	0.99
Hydrofluoric acid	Industrial and other chemicals	0.90
Crude oil	Crude petroleum and natural gas	0.88
Heating pump 160 kW	Engines and turbines	0.70

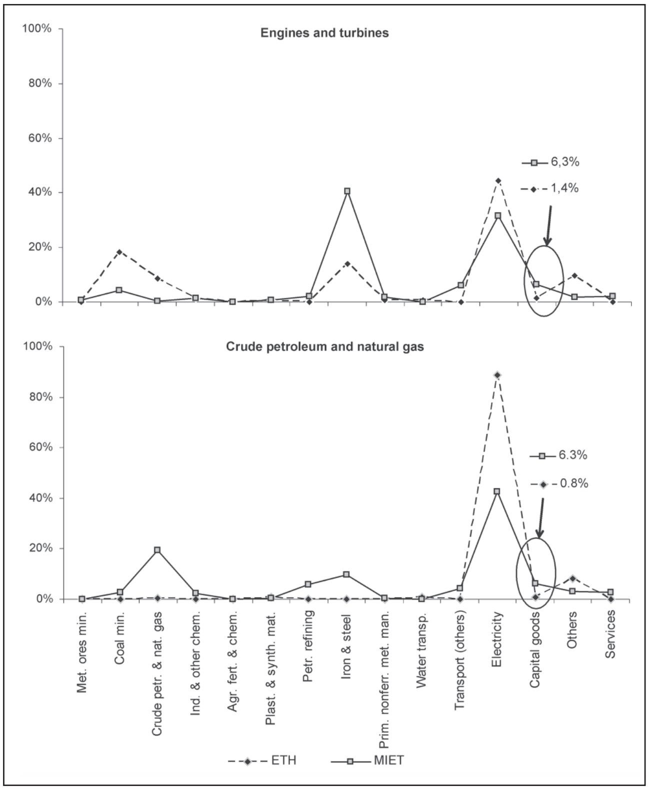

Fig. 2: Input structure expressed in embodied CO_2

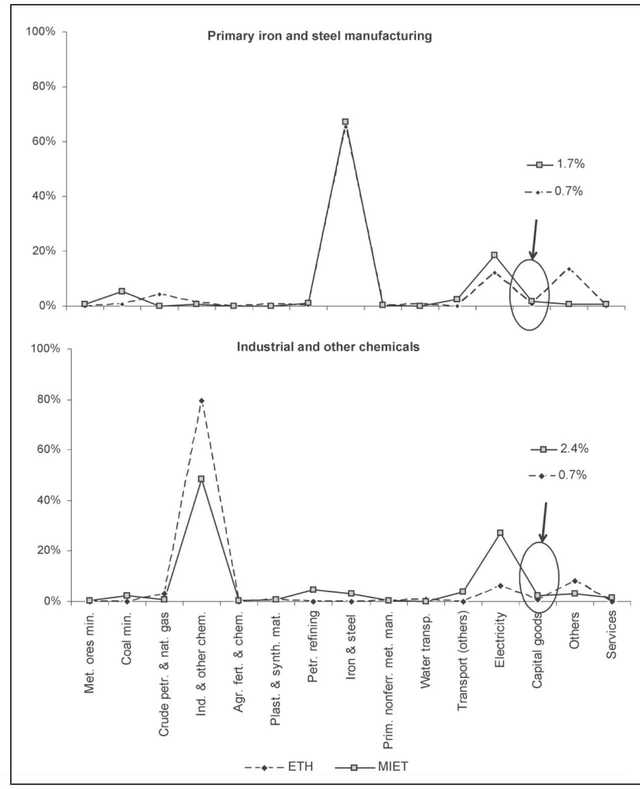

Fig. 3: Input structure expressed in embodied CO_2

It may be observed that underestimation or overestimation by MIET relative to ETH or *vice versa* occurs quite irregularly. The CO_2 emission contributions by electricity production, for instance, are higher in MIET for 'Primary iron and steel manufacturing' and 'Industrial and other chemicals' systems, but the opposite is true for 'Engines and turbines' and 'Crude petroleum and Natural Gas' production systems.

Interestingly, however, the patterns of underestimation or overestimation by one relative to the other are rather persistent for some categories, indicating systematic common underlying roots. For instance, the contribution by the 'Capital goods' category in ETH is consistently underestimated; the differences in its percentage of contributions to other sectors between MIET and ETH range from a minimum of twofold to a maximum of almost eightfold. The input structure comparison depicted in Figs. 2 and 3 reveals two other consistently under-estimated sectors, viz. 'Transport (others)' and 'Services', although with a smaller magnitude.

3.3 Output structure study

The relative contribution, in terms of embodied CO_2, by a commodity as an input to all processes is of concern in the output structure analysis. In order to extract unique output structures of important commodities, we performed a row-wise comparison between matrices E and M^*, which result from Eqs. (6) and (7).

Fig. 4 depicts the output structures of a few important commodities of the two databases that allows us a generic comparison between the two. The continuous line represents the relative contribution of the selected input over the IO sectors, thus referring to MIET's output structure. ETH's output structure is represented by the dots, which show the relative contribution of the same selected input over the processes in ETH. Note here that there is no aggregation between the ETH processes here as well, which results in multiple dots in the same sector categories. The processes in ETH have been reclassified (but not aggregated) in order to follow the IO classification scheme, which is why each IO sector has several corresponding processes in ETH.

The position of the continuous line relative to the dots provides indications about the estimation of the output structure in the two databases. In particular, if the continuous line (MIET) crosses the dots (ETH), it implies that the two databases have a highly similar output structure for the selected input. If the continuous line stays below or above the cloud of dots it implies that the selected input by the processes in ETH database is systematically underreported or over reported, respectively or *vice versa* for MIET.

For the sake of legibility, the results have been plotted using the logarithmic scale on the y-axis, and consider only the shared and most important sectors and processes. In particular, the agricultural, forestry, fishery and tertiary sectors have been excluded. The values are in inverted order.

The output structure of 'Industrial and Other Chemicals' in Fig. 4 shows remarkable similarities between the two databases. The output structure of the 'Primary iron and steel manufacturing' and 'Electronic components' sectors, however, is clearly and systematically underreported in ETH,

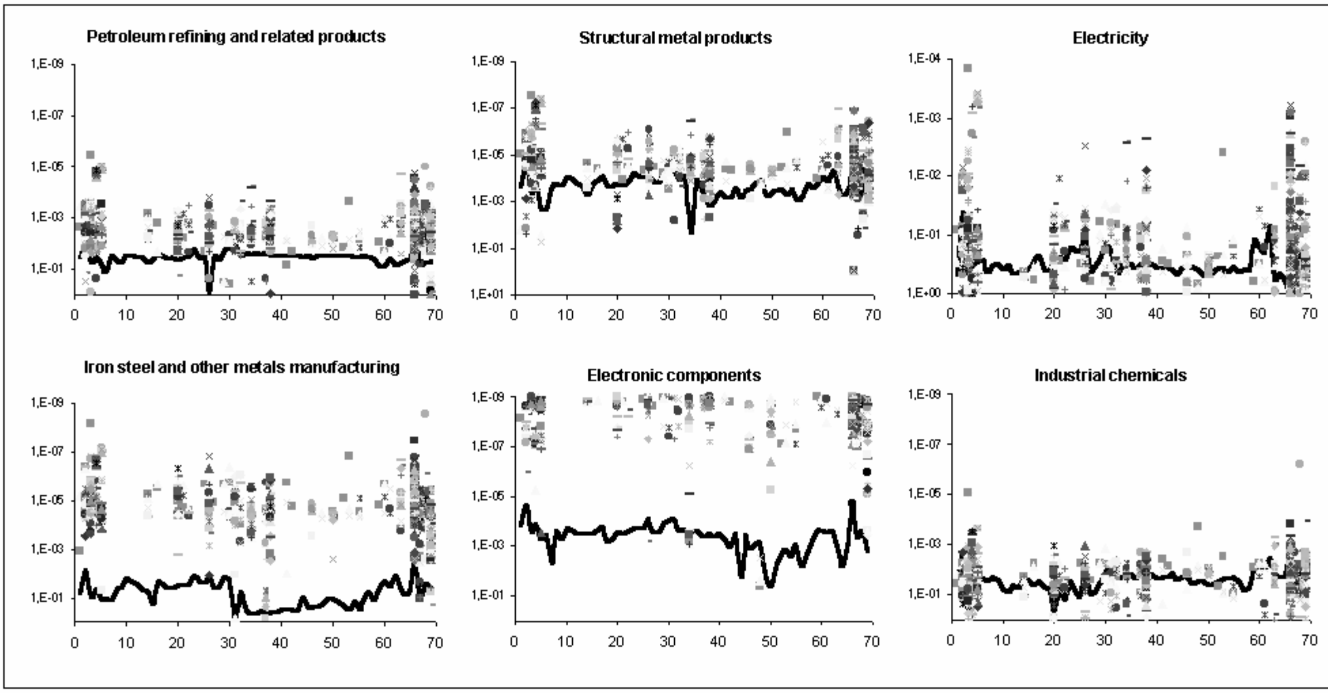

Fig. 4: Results of the output structure study

since the continuous line stays below the majority of dots. In other words, in ETH database, the importance of these two inputs to 1163 processes, are systematically underreported in ETH databases as compared to MIET database. Similar observation can be made for the 'Petroleum refining and related products' and 'Structural metal products' sectors although its magnitude may be smaller. Note that, the continuous line represents the average of each sector, which could be made up by the combination of individual processes that belongs to the sector. If the continuous line is outside the range of the vertical clouds shown in figure 4, however, any combination of the individual processes can make up the value of continuous line as an average.

4 Discussion and Conclusions

The methodological approach used in the present study permits a structural comparison between MIET and ETH, which is based on relative rather than absolute differences, as the latter might be due to a variety of random variables besides more systematic roots.

The generally high R^2 values found in the column-wise correlation suggest that MIET and ETH have similar input structures. Moreover, the row-wise results shown in Fig. 4 reveal that a typical process-LCA database, such as ETH, probably leads to an underestimation of the overall LCI due to cut-offs. One of the main sources of incompleteness of ETH is the treatment of capital goods as inputs. A typical sector providing infrastructures and capital goods generally presents a large truncation in the ETH database, as is shown by both the column- and row-wise comparisons. In Figs. 2 and 3, which show input structure comparisons, the underestimation of capital goods as input is up to eightfold lower in ETH than in MIET. A similar observation can be made for the underestimation of steel in the input structure of 'Engines and turbines' shown in the first graph of Fig. 2. More generally, the use of steel as input is subject to systematic underestimation in ETH (see Fig. 4). These conclusions are further confirmed by the row-wise comparison shown in Fig. 4, which in the case of 'Electronic components' indicates a significant underestimation. Figs. 2 and 3 of the present study reveal another source of incompleteness, which is the consistent underestimation of transport activities as input in ETH compared to MIET.

Input-Output analysis has been proposed as an alternative model to LCA, since it is a top-down technique and it allows the entire economy to be considered as a system under study [2,3]. Although this completeness is undoubtedly an advantage, the Input-Output methodology suffers from several limitations, mainly due to the level of aggregation of the sectors, which are not suitable for detailed analyses [10]. The use of Input-Output analysis as an alternative way to carry out an LCI would not be relevant for detailed LCA studies, especially for atypical goods that cannot be approximated by a sector in an Input-Output table. However, expanding the analysis to the entire economy and objectively solving the boundary definition problem is a necessary improvement for LCI, which can be obtained by the complementary use of process-LCA and an IO table with corresponding environmental data, such as MIET. Thus it is highly desirable to explore the intersection between the two approaches through hybrid analysis [7,8,12,15]. Hybrid analysis maximises the strengths of the two approaches while retaining process specificity and broadening the system boundary without much cost. The development of hybrid LCI databases and software tools that enable such analyses would be an important step forward.

International efforts to improve and harmonise the Input-Output LCI databases is another area that needs more attention. Currently, a dozen Input-Output LCI databases are available around the world (see ref. [8] for a survey). However, the level of sectorial detail and the quality of environmental emission data differ significantly between databases. A co-ordinated effort to build a set of common protocols and quality indicators between databases is highly desirable, the UNEP/SETAC Life Cycle Initiative being one of the options.

Some recent developments are relevant for the contents of this paper. The ETH 96 database has been substantially improved and a new version, EcoInvent 2000, is now available. The MIET database has been updated as well, using 500×500 US IO data for 1998 and various environmental emissions, resource use and land use data that amount to 1344 items. The new version, MIET 3.0, is now available as part of the SimaPro software package by PRé Consultants or directly from CML with a software tool, Comprehensive Environmental Data Archive (CEDA) 3.0 [31]. Thus, it will be interesting to apply the structural comparison method presented in this paper to the new databases as well.

Background information: Appendix 1 – Column wise R^2 coefficients (only the R^2 coefficients higher than 0.6) (Online only, go to: http://dx.doi.org/10.1065/lca2004.12.198)

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Appendix 1: Column wise R^2 coefficients (only the R^2 coefficients higher than 0.6)

	Coal mining	Crude petroleum and natural gas	Non-metallic minerals mining	Industrial and other chemicals	Rubber and miscellaneous plastics products	Primary iron and steel manufacturing	Primary nonferrous metals manufacturing	Engines and turbines
Coal mining	0.84							
Crude oil (1)		0.88						
Crude oil (2)		0.88						
Natural gas (1)		0.88						
Natural gas (2)		0.90						
Aluminium 100% Rec.							0.82	
Bentonite			0.82					
Lead							0.62	
Zinc for Plating							0.63	
Chemical organic				0.78				
Ethylene glycol\oxid				0.89				
Formaldehyde				0.89				
Hydro fluoric acid				0.90				
Electro steel						0.99		
Rubber EPDM					0.89			
Manganese							0.61	
Propylene glycol					0.61			
Polystyrol					0.91			
PE (LD)					0.71			
Heating pump 160 kW								0.70
Heating pump 30 kW								0.64
Gas motor								0.60
Natural gas transport (1)								
Natural gas transport (2)								
Natural gas transport (3)								
Laminat m-Si								
m-Si Lam								
m-Si Pan								
p-Si Lam								
m-Si Wafer								
m-Si Cell								
Power plant-infrastructure (1)								
Power plant-infrastructure (2)								
Coal extraction machinery								
Lift truck								
Truck 40t								
Crude oil -pipes and freight (1)								
Crude oil -pipes and freight (2)								
Waste treatment (1)								
Waste treatment (2)								
Waste treatment (3)								
Nuclear power plant infra. (1)								
Nuclear power plant infra. (2)								

Appendix 1: Column wise R^2 coefficients (only the R^2 coefficients higher than 0.6) (*cont'd*)

	Gas production and distribution	Electronic components	Electrical industrial equipment and apparatus	Farm, construction, and mining machinery	Truck and bus bodies, trailers, and motor vehicles parts	Pipelines, freight forwarders, and related services	Water and sanitary services	New construction
Coal mining								
Crude oil (1)								
Crude oil (2)								
Natural gas (1)								
Natural gas (2)								
Aluminium 100% Rec.								
Bentonite								
Lead								
Zinc for Plating								
Chemical organic								
Ethylene glycol\oxid								
Formaldehyde								
Hydro fluoric acid								
Electro steel								
Rubber EPDM								
Manganese								
Propylene glycol								
Polystyrol								
PE (LD)								
Heating pump 160 kW								
Heating pump 30 kW								
Gas motor								
Natural gas transport (1)	0.89							
Natural gas transport (2)	0.89							
Natural gas transport (3)	0.82							
Laminat m-Si		0.85						
m-Si Lam		0.76						
m-Si Pan		0.86						
p-Si Lam		0.87						
m-Si Wafer		0.86						
m-Si Cell		0.88						
Power plant-infrastructure (1)			0.65					
Power plant-infrastructure (2)			0.67					
Coal extraction machinery				0.65				
Lift truck				0.62				
Truck 40t					0.81			
Crude oil -pipes and freight (1)						0.98		
Crude oil -pipes and freight (2)						0.98		
Waste treatment (1)							0.62	
Waste treatment (2)							0.69	
Waste treatment (3)							0.73	
Nuclear power plant infra. (1)								0.76
Nuclear power plant infra. (2)								0.76